U.S. ARMY RESEARCH INSTITUTE OF
ENVIRONMENTAL MEDICINE

USARIEM TECHNICAL REPORT T00-23

DATE August 2000
AD

SUBJECTIVE SYMPTOMOLOGY AND POSTURAL CONTROL DURING SIMULATION OF A SURVIVAL ENVIRONMENT ABOARD A DISABLED SUBMARINE

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

U.S. ARMY MEDICAL RESEARCH AND MATERIEL COMMAND

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 2000	Technical report

4. TITLE AND SUBTITLE
Subjective symptomology and postural control during during simulation of a survival environment aboard a disabled submarine

5. FUNDING NUMBERS

6. AUTHOR(S)
Allen Cymerman, Andrew J. Young, T.J.R. Francis, Douglas D. Wray, Dan T. Ditzler, Dean Stulz, Maria Bovill, and Stephen R. Muza

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick
Frederick, MD 21702-5012

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Subjective symptoms and postural control were assessed in 7 submariners during 5 days exposure to a simulated disabled submarine environment (DISSUB) (4C, 2.5% carbon dioxide, 16.75% oxygen, 85% humidity). Daily morning symptoms were assessed using factor scores from the Environmental Symptoms Questionnaire. Postural instability was measured using an unstable platform balance system. Three 30-sec postural tests were performed a total of 4 times: preconditions, after 66 h and 114 h of exposure, and post conditions. Cold stress factor scores increased after 24 h, peaked at 48 h, and declined thereafter. Muscle discomfort score increased until 168 h and then declined. Postural instability increased after 66 h. This increase declined after 114 h and returned to baseline after conditions ended. Increased symptom severity occurred in conjunction with an impairment in postural stability, and normalcy was regained after cessation of experimental conditions. Impairment in postural control was most likely due to an effect on peripheral control mechanisms that were sensitive to cold exposure and not to central effects of high CO2 and/or low O2. The combination of cold, hypercapnia and hypoxia can result in disturbances in postural control such that submariners' performance on crucial tasks involving mobility and balance may be impaired.

14. SUBJECT TERMS
Hypoxia, Hypercapnia, Postural Control, Environmental Symptoms Questionnaire

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

USARIEM TECHNICAL REPORT T00-?

SUBJECTIVE SYMPTOMOLOGY AND POSTURAL CONTROL DURING SIMULATION OF A SURVIVAL ENVIRONMENT ABOARD A DISABLED SUBMARINE

Prepared by

Allen Cymerman[1]
Andrew J. Young[1]
T.J.R. Francis[3]
Douglas D. Wray[3]
Dan T. Ditzler[1]
Dean Stulz[1]
Maria Bovill[2]
Stephen R. Muza[1]

[1]Thermal and Mountain Medicine Division, USARIEM
[2] Military Nutrition Division, USARIEM
[3] Naval Submarine Medical Research Laboratory

August 2000

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

BACKGROUND

This research effort is the result of a collaborative investigation by investigators from the U.S. Army Research Institute of Environmental Medicine, Natick, MA, and the Naval Submarine Medical Research Laboratory, Groton, CT. The principal purpose was to determine the rate of carbon dioxide production of submariners aboard a disabled submarine whose ambient steady-state environmental conditions consisted of 5 days of mild hypoxia (16.75%), hypercapnia (2.5%), cold (4°C) , and high relative humidity (85%). In addition to this primary goal, an acute and chronic hypoxia testing phase with normal ambient carbon dioxide, temperature, and relative humidity was added at the beginning and end of the hypercapnic phase to test hypotheses relative to just the environmental stresses of mild hypoxia, inactivity, and confinement.

EXECUTIVE SUMMARY

The ambient environment of a submerged, disabled submarine can quickly become challenging to the physiological systems of a submariner. The physical environment can deteriorate with respect to temperature, humidity, carbon dioxide, oxygen, and relative darkness. The psychological environment can be one of severe confinement, inactivity, and fear. Depending on the length of time and the depth a submarine is submerged, temperature can fall to 4°C; humidity can become 85-100%; carbon dioxide levels can rise to 2.5% or higher; and oxygen levels fall to 16.5% or lower. Of all these stressors, carbon dioxide is probably the most important operationally because the capacity of a submarine's physical system to absorb carbon dioxide is limiting. The principal purpose of this investigation was to determine the carbon dioxide production of survivors aboard a simulated disabled submarine with subnormal environmental conditions. The purpose of this report is to document submariners' subjective symptoms and their ability to perform on a standard test of postural control during the course of 5 days of exposure to this environment.

Subjective symptoms to environmental stressors were assessed each morning using the Environmental Symptoms Questionnaire (ESQ). Weighted questionnaire factor scores in 10 symptom complex categories were calculated. Postural instability was measured using a computer-controlled unstable platform balance system. Subjects performed three 30-sec postural tests: static eyes open, static eyes closed, and a dynamic that combined coordination and balance. Postural tests were performed a total of 4 times: prior to entering the chamber, after 66 h and 114 h of exposure to DISSUB conditions (4°C, 2.5% carbon dioxide, 16.75% oxygen, 85% humidity), and after returning to normal environmental conditions.

None of the factor scores were statistically significant except total score, cold stress, and muscle discomfort. Total symptom score was significant only after 144 h of hypoxia. The cold stress factor scores began to increase after 24 h, peaked at 48 h, and declined thereafter. The muscle discomfort score increased steadily until 168 h and then declined. There was an increase in postural instability after 66 h of steady-state DISSUB conditions. This increase declined after 114 h and returned to base line after DISSUB conditions ended. There were no differences in the ratio eyes-closed/eyes-open.

Cold stress and muscle discomfort were the principal symptoms reported. The increase in symptoms occurred in conjunction with an impairment in postural stability. Normalcy was regained after cessation of environmental conditions. The impairment in postural control was most likely due to an effect on peripheral control mechanisms and reflexes that were sensitive to cold exposure and not to central effects of high carbon dioxide and/or low oxygen. The combination of cold, hypercapnia, and hypoxia when present for a moderate period of time and severity, can result in disturbances in postural control such that submariners' performance on crucial tasks involving mobility may be impaired.

INTRODUCTION

Submariners exposed to altered ambient environmental conditions aboard a submerged, disabled submarine must be able to perform complex tasks as part of their normal duties, as well as during crisis periods when emergency actions are required or imminent. Prior to initiation of a requisite activity, survivors under DISSUB conditions will probably keep all physical movements to a minimum in order to conserve resources. Nevertheless, it is inevitable that the oxygen level and temperature decrease, and the CO_2 and humidity levels increase. In order to simulate the environmental conditions aboard a disabled submarine that approximate those that may develop during a submerged situation, ambient, steady-state conditions of hypoxia (16.75%), hypercapnia (2.5%), and cold (4°C) were produced and maintained for 5 consecutive days in a hypobaric chamber at normal barometric pressure (760 mmHg) (DISSUB). The principal purpose of this study was to obtain an estimate of submariner carbon dioxide production because carbon dioxide production is one of the critical factors in determining survivability aboard such a disabled vessel. The experimental design also allowed us to test the additive or synergistic effects of the combined stresses on subjective symptomology and postural control.

Exposure for several days to the environmental and operational conditions of DISSUB (i.e., mild hypoxia, cold, hypercapnia and high humidity) can have specific detrimental effects on subjective symptoms and motor functions. Previous psychomotor studies of exposure to hypercapnic environments usually involved levels of hypercapnia ranging from 1.2% to 6% and exposure times of minutes to days (5,9). Manzey and Lorenz observed that visuomotor tasks involving eye-hand coordination can be affected by carbon dioxide concentrations as low as 1.2% if subjects are chronically exposed for 26 days, but they concluded that the strength of the effect was not operationally significant (9). Studies of the effects of shorter duration and higher carbon dioxide concentrations on behavior or psychomotor function are sparse. Henning et al. (5) demonstrated that breathing 6% carbon dioxide for several minutes resulted in significant changes in several behavioral tests, including body sway, after the actual exposure period but not during. They concluded that individuals could be at risk immediately after a short, high-level carbon dioxide exposure. Fothergill et al. (2) observed significant decrements in cognitive and psychomotor performance within minutes of exposure to 8%, but not 4% carbon dioxide. Psychomotor studies of long-term exposures to the moderately hypercapnic atmosphere of 2.5% are lacking.

Long-term effects of mild hypoxia (16.75% oxygen) on psychomotor performance are sparse, probably because this level of hypoxia is not very severe. Many research studies suggest that there is little or no disruption of psychomotor performance below altitudes of 10,000 ft.. However, some studies have reported equivocal results on several mental and psychomotor tests that may be dependent on factors such as the specific tasks being measured, the length of exposure time, and the degree of training (6)(1). Because symptoms such as dizziness and disequilibria may be very sensitive indicators of hypoxia, tests associated with these phenomena may provide functional correlates that underlie physiological mechanisms that are affected by a small change in ambient oxygen levels. Such

is the case if studies by Fraser et al. (3) and Nordahl et al. (10) are valid. Both studies found significant detrimental effects at altitudes of 8,000 ft; Fraser et al. found effects as low as 5,000 ft. However, exposure times were limited to only 30 and 14 min, respectively. Only anecdotal evidence is available on balance and postural stability during relatively longer exposures to moderate and high terrestrial altitudes. This evidence has been obtained on trekkers probably suffering high altitude cerebral edema (4). The effect of the possible additive or synergistic combination of the stress conditions existent during DISSUB (cold, hypoxia, hypercapnia, and inactivity) on postural control is unknown.

Similarly, effects of whole-body cold exposure and/or hypercapnia on postural stability are relatively nonexistent. Magnusson et al. (7,8) exposed feet to cold temperatures and found that body-sway velocity increased significantly during hypothermia when compared to normothermal conditions. The difference in body-sway between conditions was less prominent when the subject's eyes were open. However, the hypothermic stress on the feet lasted only minutes. If a significant portion of postural control is dependent on feedback from peripheral receptors in the feet and legs and if DISSUB conditions produce local hypothermic effects, then control of posture and equilibrium should be adversely affected.

There are no publications on postural stability that have incorporated the conditions of mild hypoxia, hypercapnia, and total-body cold exposure for 5 days. Nevertheless, it is quite likely that some component(s) of the postural control system, whether it is the visual, vestibular, and proprioceptive feedback and/or reflexive and voluntary muscle responses, will be detrimentally affected.

METHODS

SUBJECTS

Eight military subjects who were submariners were recruited from the U.S. Naval Submarine Base, New London, CT. Physical exams and medical histories were considered normal. Each subject was fully informed of the nature of the study, gave written consent, and was made aware of his right to withdraw without prejudice at any time.

EXPERIMENTAL DESIGN

This study had a repeated measures design and was conducted in seven consecutive atmospheric phases as described below and in Table 1:

1. pre-exposure control phase (48 h) with normal ambient conditions (21% oxygen, 0.04% carbon dioxide, 50% rel. hum., and 22°C)
2. acute hypoxia (16.75%) with other ambient conditions normal
3. environmental transition to DISSUB conditions
4. steady-state DISSUB phase
5. environmental transition (5 h) back to 0.04% carbon dioxide, 50% rel. hum., and 22°C

6. continued hypoxia (16.75%) with other ambient conditions normal
7. postexposure control phase

Table 1. DISSUB Environmental Conditions and Testing Schedule

Phase	Hour	Environmental Conditions and Test Performed	Duration Hypoxia*	Duration DISSUB**
Pre-exposure Control (1a,b,c)	1600	ESQ	A	
	0600	ESQ	B	
	1400	Postural Instability		
	0600	ESQ	C	
	1400	Postural Instability		A
Acute Hypoxia (2)	0215-0530	Ramp down to 16.75% O_2		
	0600	ESQ	1	
Transition to DISSUB (3)	1500	24-h Ramp to 2.5% CO_2, 4°C, 85% r.h.		
	0600	ESQ	24	
	1500	Start of Steady-State DISSUB Conditions		
Steady-State DISSUB Conditions (4)	0600	ESQ	48	
	1500			
	0600	ESQ	72	
	1500			
	0600	ESQ	96	
	0930	Postural Instability		66
	1500			
	0600	ESQ	120	
	1500			
	0600	ESQ	144	
	0900	Postural Instability		114
End DISSUB Conditions (5)	1500	End 2.5% CO_2, 4°C, 85% r.h.		
Continued Hypoxia (6)	0600	ESQ	168	
	0800	Postural Instability		135
	1300	End 16.75% O_2		
Postexposure Control (7)	0600	ESQ	Post	B
	1245	Postural Instability		

*Numbers indicate elapsed exposure hours when ESQ was administered.
**Letters indicate when balance instability tests were performed. Numbers indicate elapsed hours from the beginning of DISSUB steady-state conditions.

SUBJECTIVE SYMPTOMOLOGY

Subjective symptoms to environmental stressors were assessed using the ESQ. The questionnaire was developed to determine the effects of exposure to environmental extremes such as heat, cold, and high terrestrial elevation (11-13,15). Questionnaire weighted scores (factor scores) have been developed and validated for acute mountain sickness-cerebral, acute mountain sickness-respiratory, ears-nose-throat, cold stress, distress, alertness, exertion, muscle discomfort, and fatigue. Using these factor scores, the ESQ was ideal for the

measurement of subjective multistress-induced symptoms. The ESQ was administered every morning at approximately 0600 h.

POSTURAL INSTABILITY

Subjects were screened for any significant lower extremity injury or equilibrium dysfunction. Postural instability was assessed using a computer-controlled unstable platform balance system (K.A.T. 2000, O.E.M. Medical, Carlsbad, CA 92008). The balance consisted of a 60-cm circular platform (15 cm above the floor) whose ease of tilting was controlled by varying the pressure in a pneumatic bladder situated around a central pivot point. The bladder was adjusted for ambient pressure and subject weight. A balance index was automatically derived from a tilt sensor that measured the absolute distance between the tilted position and a reference point. The balance score was thus inversely proportional to balancing skill. A handrail was situated about 45° to the left and right of the subject's midline.

Subjects performed three 1-minute balance tests that they had practiced previously. They performed each test barefooted (or in socks) with their arms akimbo and their feet approximately 25 cm apart, equidistant from a central pivot point. They received computer feedback by way of a moving X that indicated the position of the platform. They were instructed to keep the platform as level as possible by keeping the X in the center of a bulls-eye (eyes-open static test). The second test was the same except that the subject's eyes were closed (eyes-closed static test). During the third test (dynamic test), subjects stood as before but were required to move the platform in a circular pattern so as to 'chase' a computer-controlled moving object. Each of the tests lasted approximately 30 s. Tests were performed in the same order for all subjects.

Subjects were tested a total of 4 times: once prior to entering the chamber (phase 1), after 66 h and 114 h of exposure to DISSUB conditions (phase 4), and after returning to normal environmental conditions (phase 7) (see Table 1).

STATISTICS

Data were analyzed using repeated-measures ANOVA followed by a Tukey *post-hoc* test for critical differences. A statistical probability value of $p \leq 0.05$ was accepted as significant. Values are presented as mean ± standard deviation (sd).

RESULTS

SUBJECTS

Of the eight military subjects that were initially recruited from the U.S. Naval Base, New London, CT, one withdrew voluntarily for personal reasons. Table 2 lists the subjects' initial physical characteristics.

Table 2. Physical Characteristics.				
Subject	Age (yr)	Height (cm)	Weight (kg)	PSI*
1	42	174.5	94.5	3.0
2	26	177.0	72.7	2.4
3	27	166.0	70.9	3.0
4	27	175.0	87.3	3.0
5	29	173.0	81.4	2.5
7	36	178.5	95.0	4.0
8	36	176.5	78.2	2.8
Mean ± s.d.	31.8 ± 6.1	174.4 ± 4.1	82.9 ± 9.8	

* PSI is derived from a pressure meter that indicates the inflation bladder pressure. It is not meant to be accurate, but is characteristic of each subject's rough balance ability. Once established, the PSI setting is kept the same for each subject. Bladder pressure is indirectly proportional to balance ability.

ESQ RESULTS

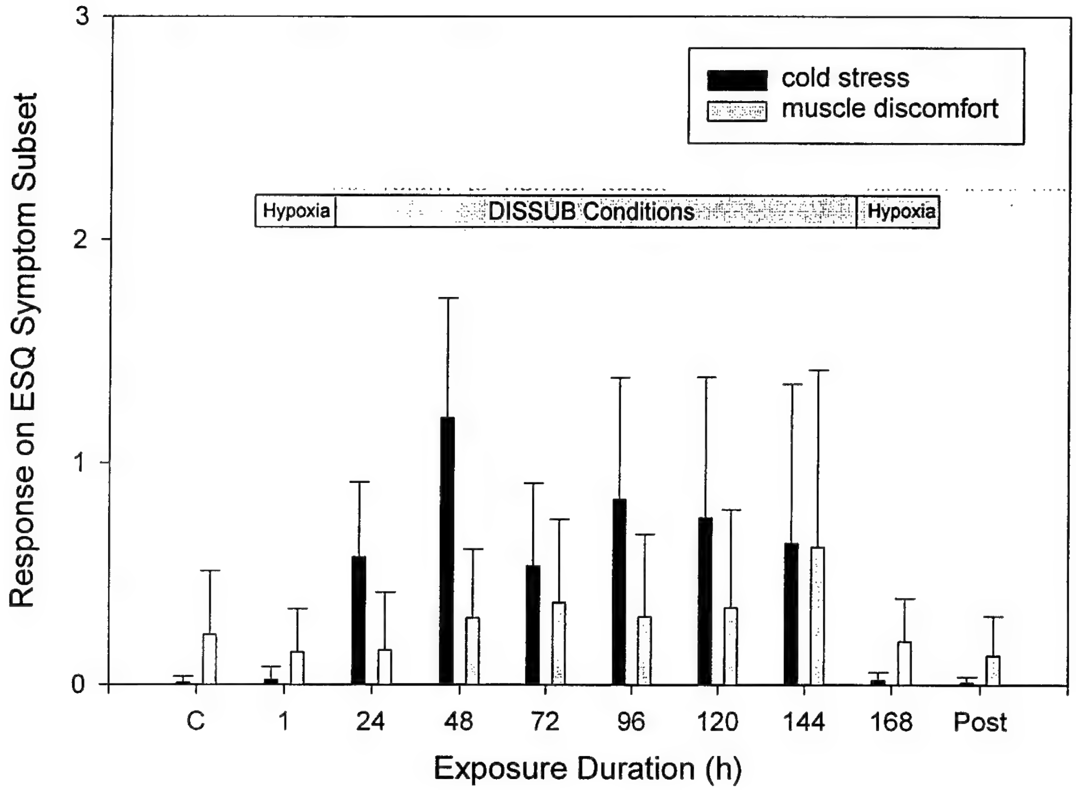
The 68-item ESQ is factored into nine different symptom complexes: acute mountain sickness (see page 4). A 10th factor of total symptom score is included. Mean scores and standard deviations are shown in Table 3. Questionnaires administered during control periods A and B are not used in the statistical calculations. None of the symptom complex scores were statistically significant except total score, cold stress, and muscle discomfort. The time course for cold stress and muscle discomfort are shown in Figure 1. Total symptom score was significant only after 144 h of hypoxia when compared with the 1-h value. The cold stress factor scores began to increase after 24 h ($p=0.06$), continued to increase at 48 h ($p=0.001$), and declined thereafter ($p=0.123$). Muscle discomfort score increased steadily until 168 h ($p=0.023$) and then declined (Figure 1).

Table 3. Subjective Environmental Symptoms Questionnaire Responses during the Disabled Submarine Protocol

Symptom Complex	ENVIRONMENTAL CONDITIONS †										
	1a	1b	1c	2	3	4	4	4	4	4-5	6	7
	Control A	Control B	Control C		SS Transition	SS15h	SS 39h	SS 63h	SS 87h	SS 111h SS End		Post Exposure
				1h Hypox	24h	48h	72h	96h	120h	144h	168h	
Total Score	8.43±9.25	9.00±7.48	11.43±11.41	6.86±6.12	10.43±6.55	21.29±14.23	16.57±10.92	19.71±16.63	17.57±16.48	25.14±28.53‡	13.29±13.76	11.00±13.32
ESQ-C	0.08±0.14	0.07±0.09	0.05±0.13	0.04±0.09	0.08±0.11	0.40±0.91	0.15±0.14	0.18±0.18	0.07±0.10	0.36±0.65	0.07± 0.13	0.16±0.20
ESQ-R	0.10±0.11	0.15±0.14	0.20±0.21	0.16±0.24	0.12±0.12	0.25±0.20	0.22±0.21	0.19±0.22	0.16±0.16	0.27±0.33	0.20±0.20	0.18±0.20
ENT	0.13±0.26	0.30±0.33	0.33±0.39	0.13±0.13	0.12±0.18	0.22±0.20	0.41±0.36	0.29±0.40	0.34±0.51	0.43±0.63	0.47± 0.56	0.36±0.58
Cold Stress	0.11±0.16	0.00±0.00	0.01±0.03	0.02±0.06	0.58±0.34	1.20±0.54*	0.54±0.37	0.84±0.55*	0.76±0.63*	0.64±0.71*	0.02±0.04	0.01±0.03
Distress	0.17±0.29	0.17±0.19	0.16±0.22	0.09±0.12	0.14±0.14	0.19±0.17	0.21±0.21	0.32±0.43	0.24±0.32	0.45±0.50**	0.18±0.25	0.20±0.29
Alertness	2.05±0.35	1.55±1.14	1.93±0.93	1.96±0.37	1.67±0.76	1.77±0.86	1.86±0.49	1.93±0.46	1.84±0.54	1.94±0.60	2.20±0.54	1.91±0.39
Exertion	0.11±0.16	0.05±0.14	0.03±0.08	0.05±0.10	0.10±0.17	0.23±0.37	0.24±0.29	0.21±0.27	0.19±0.29	0.30±0.51	0.10±0.18	0.07±0.14
Muscle Discomfort	0.12±0.16	0.16±0.17	0.23±0.29	0.15±0.20	0.16±0.26	0.30±0.31	0.37±0.37	0.31±0.37	0.35±0.44	0.62±0.80***	0.20±0.19	0.13±0.18
Fatigue	0.18±0.16	0.24±0.24	0.37±0.30	0.15±0.16	0.22±0.22	0.34±0.44	0.32±0.29	0.41±0.55	0.34±0.35	0.57±0.78	0.51±0.75	0.30±0.45

Data represent the mean ± s.d. from 7 subjects. †= see Table 1 for environmental conditions. 1h hypox = 1 h of 16.75% oxygen after previous 195-min decreasing ramp from normal ambient conditions. SS = hours of steady-state DISSUB conditions of 16.75% oxygen, 2.5% carbon dioxide, 85% r.h., and 4°C. * $p<0.001$, ** $p<0.02$, *** $p<0.004$, ‡ $p<0.002$.

Figure 1: Time Course for Development of Symptoms Due to Cold Stress and Muscle Discomfort



POSTURAL BALANCE

An increase in numerical values in Table 4 represents a decrease in postural control (an increase is indicative of a greater postural instability). With the eyes-open test, there is an increase in postural instability after 66 hours of steady-state DISSUB conditions ($p<0.001$). This increase declined after 114 hours ($p<0.01$) and returned after DISSUB conditions were discontinued, with the exception of the 16.75% oxygen condition. A similar change occurred in the eyes-closed test except that the increase in instability after 135 hours did not occur. There were no differences in the results of the dynamic test during any of the testing times. In addition, there were no differences in either the left-to-right or anterior-posterior postural control indices on any of the three balance modes during any of the test times. Neither were there differences in the ratio eyes-closed/eyes-open.

Table 4. Postural Instability Responses during the Disabled Submarine Protocol					
Test	Control A	SS66	SS114	H135	Control B
Eyes Open	30.9± 9.1	39.1±12.7*	27.2±10.3*	35.9±14.2*	20.8±9.1*
Eyes Closed	187.0±46.3	226.4±46.1‡	183.2±45.5‡	178.3±36.1‡	179.6±50.7‡
Ratio EC/EO	6.35±2.00	6.01±1.11	7.18±1.79	5.46±1.87	9.56±3.00
Dynamic	88.3±20.1	106.4±48.6	74.9±17.5	102.3±24.8	86.5±35.927

SS66 = 66 hours of exposure to DISSUB steady state conditions (16.75% oxygen, 2.5% carbon dioxide, 85% r.h., 4°C). SS114 = 114 hours and H135 = 135 continuous hours of 16.75% oxygen but return to normal temperature, carbon dioxide level and relative humidity. * = $p<0.001$ (ANOVA: SS66 vs. H135; SS66 vs. Control B; SS66 vs SS114). ‡ = $p<0.011$ (ANOVA: SS66 vs. Control B; SS66 vs SS135; and SS66 vs. H135). N= 7 subjects. Comparisons are made to the Control B data because subject training in the technique was insufficient to obtain an adequate baseline prior to initiation of environmental conditions.

There were no correlations between subjective symptomology (cold stress or muscle discomfort) and postural control measurements when the highest symptom scores were used with postural measurements closest in time. The probability closest to significance (P=0.08) was obtained after 15 h of DISSUB conditions, and the balance measurements taken after 66 h.

DISCUSSION

Confinement, cold, high carbon dioxide levels, low oxygen levels, and high humidity can all combine to produce physiological dysfunction in otherwise normal individuals. When these environmental stressors occur in unison aboard a disabled submarine, there is a finite time in which submariners can be expected to perform sophisticated cognitive and dexterous procedures. Exposures to high carbon dioxide, low oxygen, and cold have been studied individually and extensively over the years, but relatively few studies have looked at the combination of the three. It was expected that the combination could seriously hamper performance of crucial tasks and possibly endanger individual and crew lives. It was hypothesized that the subjective effect of the combination of stressors would become evident on the self-administered ESQ in both severity and temporal (exposure duration) aspects. In addition, it was hypothesized that the combination of stresses would also affect balance control.

Environmental Symptom Questionnaire scores showed significant increases in three areas: total score, cold stress, and muscle discomfort. As expected, the cold stress symptom subset increased after 24 h, reached a peak after 24 h and stabilized thereafter. Symptoms disappeared immediately after termination of DISSUB and hypoxic conditions. Muscle discomfort scores throughout the study were higher than usually observed in past chamber studies. It is possible that the confinement and inability to perform normal physical activities accounted for the higher muscle discomfort score baseline. Muscle

discomfort scores were slightly higher during the DISSUB conditions, reached a significant peak 144 h after initiation of environmental conditions, and returned to original baseline levels after cessation of environmental conditions. It is likely that cold exposure (and possibly hypercapnia) exacerbated muscle discomfort as symptoms returned to pre-exposure levels 24 h after return to normocapnia and normal ambient temperature.

There were no indications that the submariners exhibited any symptoms of Acute Montain Sickness, either the cerebral or respiratory variety, with several days' exposure to 16.75% oxygen at ambient pressure. Exposure to only hypoxic conditions 24h prior to initiation of the transition to DISSUB conditions resulted in no significant ESQ symptom scores. Likewise, after termination of DISSUB conditions but with continuation of hypoxia for another 24 hours, there were no significant ESQ symptom scores related to Acute Mountain Sickness.

Balance is the culmination of afferent feedback from the visual, vestibular, and proprioceptive senses and efferent reflexive and voluntary muscle responses. The relative importance of each of these varies in different individuals and can be modified with appropriate training. By eliminating the visual input on a two-legged static balance tests, we attempted to gauge how much a submariner relied on vision to maintain postural stability and whether this ability changed during exposure to DISSUB environmental conditions. In other words, in a darkened or dark submarine, how much worse would balance be when combined with environmental stressors? Submariners were 5-7 times worse in a cold, dark, carbon dioxide-filled, and humid room than when visual cues were present. There was no change in this relationship (eyes-closed/eyes-open ratio) during the course of DISSUB exposure conditions. Although vision is one of the first special senses to be affected by hypoxia, we did not observe any effect on postural control when visual input was eliminated and hypoxia as the sole stressor.

With increases in muscle discomfort and cold stress ESQ scores, we surmise that the root of a stability problem could be peripheral at the muscle level. The ratio eyes closed/eyes open did not change over the course of exposure, indicating that the relative importance of visual input did not change with respect to the total postural control input-output. With an increase in instability, the lack of change in this ratio would support the hypothesis that the problem arises in the periphery.

Previous studies of environmental stressors such as hypercapnia, cold and hypoxia on postural control may be difficult to relate to this study due to the imposition of the three stressors at the same time. Nevertheless, an indication of the sensitivity of postural control can be discerned from studies that have imposed singular stresses. Exposure to acute, mild, simulated altitude (5,000-8,000 ft) has been shown to result in a decreased static postural stability (i.e., the subjects were required to stand still as possible still on a stable force

plate)(3,10). Our subjects were at simulated 6,000-6,500 ft altitude, but carbon dioxide-induced hyperventilation effectively lowered the equivalent altitude to ~5,000 ft or less (~98% saturation using pulse oximetry). Although the significant detrimental effects previously observed have been attributed to effects on the central nervous system, we don't believe that a central cause was operative during DISSUB.

To our knowledge, the effects of whole body cold exposure and postural control have not been studied previously. Magnusson et al. (7,8) demonstrated the importance in postural control of mechanoreceptors in the soles of hypothermic feet. They concluded that sensory inputs from mechanoreceptors in the feet were important in maintaining postural control. The results during exposure to DISSUB condition are explainable if subjects' feet and leg muscles were cold, stiff, and hypothermic.

There is also a paucity of previous studies on hypercapnia and postural control. Most studies of psychomotor performance involved levels of carbon dioxide much higher than those imposed in DISSUB. Levels of carbon dioxide exposure in the range of 4%-8% have been shown to significantly impair performance on a number of tasks such as a modified Stoop test, arithmetic test, figure-copying tasks, a pegboard speed test, tracking, eye-hand coordination, and problem-solving ability (2,16). Henning et al. (5) studied the behavioral effects of short-term exposure (5-7 min) to 6% carbon dioxide produced by using gas mixtures and found a significant effect on body sway after exposure. They did not measure sway during exposure. Manzey and Lorenz (9) found significant impairment in a tracking performance when 4 subjects were exposed to 1.2% carbon dioxide for 26 days. However, they attributed the effect to a possible change in alertness and the performance of only 2 of the subjects. Their results were significantly lower on the first day of exposure; only one subject's performance remained consistently lower during the entire exposure. Sayers (14) studied mental performance of subjects during 20 min exposures of 4.5%-7.5% carbon dioxide and found a threshold at 5.5%. Longer exposures at these levels were not studied. From the above, we can conclude that the level of carbon dioxide used on DISSUB should not affect psychomotor or mental performance, including postural control.

CONCLUSIONS

Multistress studies such as DISSUB are uniquely designed to test specific scenarios involving actual exposures of military personnel to abnormal environmental conditions. Although the primary purpose of DISSUB was to obtain an accurate estimate of the carbon dioxide production aboard a disabled submarine, this study afforded the opportunity to examine subjective symptomology and postural control in 7 submariners who were exposed to the confinement, above-normal carbon dioxide, below-normal oxygen levels, low

temperature, and high humidity that would likely occur in an actual submarine crisis situation.

Cold stress and muscle discomfort were the principal symptoms reported. The increase in symptoms occurred in conjunction with an impairment in postural stability. This impairment was most likely due to an effect on peripheral control mechanisms and reflexes sensitive to cold exposure and not to central effects of high carbon dioxide and/or low oxygen. Symptoms and postural control returned to normal within 24 h of normal environmental conditions. The combination of cold, hypercapnia, and hypoxia, when present for a moderate period of time and severity, can result in disturbances in postural control such that submariners' performance on crucial tasks involving mobility may be impaired.

REFERENCES

1. Banderet, L. E., and R. L. Burse. Effects of high terrestrial altitude on military performance. In: *Handbook of Military Psychology*, edited by R. Gal and A. D. Mangelsdorff. New York: John Wiley & Sons, 1991, p. 233-254.

2. Fothergill, D. M., D. Hedges, and J. B. Morrison. Effects of CO_2 and N_2 partial pressures on cognitive and psychomotor performance. *Undersea Biomed. Res.* 18: 1-19, 1991.

3. Fraser, W. D., D. E. Eastman, M. A. Paul, and J. A. G. Porlier. Decrement in postural control during mild hypobaric hypoxia. *Aviat. Space Environ. Med.* 58: 768-772, 1987.

4. Hackett, P. H. *Mountain Sickness: Prevention, Recognition, and Treatment.* Albany, CA: Mountain Travel Inc., 1978, p. 4-33.

5. Henning, R. A., S. L. Sauter, E. H. Lanphier, and W. G. Reddan. Behavioral effects of increased CO_2 load in divers. *Undersea Biomed. Res.* 17: 109-120, 1990.

6. Knight, D. R., C. L. Schlichting, C. S. Fulco, and A. Cymerman. Mental performance during submaximal exercise in 13 and 17% oxygen. *Undersea Biomed. Res.* 17: 223-230, 1990.

7. Magnusson, M., H. Enbom, R. Johansson, and I. Pyykko. Significance of pressor input from the human feet in anterior-posterior postural control. The effect of hypothermia on vibration-induced body- sway. *Acta Otolaryngol. (Stockh.)* 110: 182-188, 1990.

8. Magnusson, M., H. Enbom, R. Johansson, and J. Wiklund. Significance of pressor input from the human feet in lateral postural control. The effect of hypothermia on galvanically induced body-sway. *Acta Otolaryngol. (Stockh.)* 110: 321-327, 1990.

9. Manzey, D. and B. Lorenz. Joint NASA-ESA-DARA Study. Part three: effects of chronically elevated CO2 on mental performance during 26 days of confinement. *Aviat. Space. Environ. Med.* 69: 506-514, 1998.

10. Nordahl, S. H., T. Aasen, J. O. Owe, and O. I. Molvaer. Effects of hypobaric hypoxia on postural control. *Aviat. Space. Environ. Med* 69: 590-595, 1998.

11. Sampson, J. B., A. Cymerman, R. L. Burse, J. T. Maher, and P. B. Rock. Procedures for the measurement of acute mountain sickness. *Aviat. Space Environ. Med.* 54: 1063-1073, 1983.

12. Sampson, J. B., and J. L. Kobrick. The environmental symptoms questionnaire: revisions and new field data. *Aviat. Space Environ. Med.* 51: 872-877, 1980.

13. Sampson, J. B., J. L. Kobrick, and R. F. Johnson. Measurement of subjective reaction to extreme environments: the environmental symptoms questionnaire. *Mil. Med.* 6: 215-233, 1994.

14. Sayers, J. A., R. E. A. Smith, R. L. Holland, and W. R. Keatinge. Effects of carbon dioxide on mental performance. *J. Appl. Physiol.* 63: 25-30, 1987.

15. Stamper, D. A., R. T. Sterner, and S. M. Robinson. Evaluation of an acute mountain sickness questionnaire: Effects of intermediate-altitude staging upon subjective symptomatology. *Aviat. Space Environ. Med.* 51(4): 379-387, 1980.

16. Storm, W. F., and C. L. Giannetta. Effects of hypercapnia and bed rest on psychomotor performance. *Aerosp. Med.* 45: 431-433, 1974.